Variability of the rheological and sedimentological behavior of rougher flotation tailings

The relationship between mineralization zone characteristics and tailings operational behavior (thickening, conveyance and deposit) has scarcely been studied despite its being a matter of obvious interest.

The variability of minerals of different lithology combinations and alteration at certain hypogene mineralization zones is reflected in their rheological and sedimentological behavior.

In order to advance in defining this functional relationship, an extensive study has been performed on mineral tailings of known origin and mineralogical characteristics, which have undergone rougher flotation treatment.

This study included determining solid density, particle-size distribution, settling velocity and rheograms of over two hundred samples. Settling velocities were determined by pipe tests, and the results were statistically analyzed and interpreted using the Richardson and Zaki (1954) model. The rheograms were obtained by means of a coaxial cylinder rheometer provided with devices that prevent particles from settling.

Interpretation of the results was done by adjusting to Bingham’s (1922) viscoplastic model. Plastic viscosity was adjusted to the Krieger and Dougherty (1959) model, and the yield stress, to the model of Heymann et al. (2002).

The results made it possible to statistically show the variability of the respective parameters regarding the sedimentology and rheology of the tailings. The statistical bands constitute an important component in the definition of solid design bases for engineering of the facilities in which the tailings proceeding from the studied deposit are handled.
INTRODUCTION

The mine-to-mill concept implies integrating mine operations (drilling and blasting) and plant operations (milling and classifying) in order to obtain maximum return on investment as a result of the integrated operation of processes. However, tailings handling is generally not included, and thickening, transport and deposition unit-operations and their relationship to mineralogy are not analyzed. Because of this, the mine-to-deposit or mine-to-market concept would be more representative of the entire operations.

The complexity and variability of deposits is often great. In order to deal with this issue it is possible to divide mineral deposits into different zones or domains of similar lithologies and alteration.

Associating mineralogy with the dynamic behavior of tailings is of interest to metallurgical engineers. For this purpose, a methodology has been defined that includes physical characterization (density and particle-size distribution) and rheological and settling testing of tailings whose origin and geological classification are clearly specified.

The rheological study provides information that enables designing transport lines and tailings disposal. On the other hand, the settling velocity is an indispensable parameter when defining the thickener unit area.

Connecting the mineralogy of the deposit to the rheological and sedimentological behavior of the tailings will provide a tool that will allow designing tailings transport, thickening and deposition systems with more accuracy.

This paper presents the methodology employed by the Laboratorio de Caracterización de Pulpas (Slurry Characterization Laboratory) of the Centro de Investigación de JRI (JRI Research Center) and the results obtained from the characterization of tailings originating from the flotation of ores of the hypogene zone of a deposit. The results of this study have been grouped according to the lithology and alteration of the ore zone, and this has enabled determination of the variability of each parameter according to its geological classification.

MATERIALS AND METHOD

This paper focuses on the analysis of the behavior of tailings from ores of the hypogene zone of a deposit. Two hundred and fifty rougher tailings samples were studied and grouped into ten sets based on the lithology and alteration of the already floated ore. The number of samples available per each lithology and alteration group (named LA) is proportional to its abundance in the studied deposit zone.

The tailings come from laboratory standardized flotation tests in 1 L cells. The samples are characterized in terms of solid density, particle-size distribution, rheograms, and settling velocity determinations.

Solid density was determined by gravimetrics, using a Gay-Lussac pycnometer. Particle-size distribution curves were obtained using a standardized laser analyzer in compliance with the BS-ISO 13320 standard. The rheological tests were conducted in a Searle-type coaxial cylinder rheometer.
Rheological measurements used a helical rotor, which prevents sedimentation of the solids while performing the test. In order to obtain viscosity and yield stress, the torque and angular velocity were processed by using an ad hoc algorithm with RHEOCIPS software developed by the Centro de Investigación JRI.

Settling testing was done in 1 L, 40 cm high graded graduated glass cylinders, recording the interface height through time.

Both determinations, rheology and settling, were conducted at different concentrations of solids, using process water, with and without added flocculant. The tests were conducted at pH 10, adjusting this value with lime suspensions if necessary.

The errors of each of the methods that were used are determined and validated according to detailed specific protocols for each method.

RESULTS AND DISCUSSION

Solid Density

The solid density results of the tailings were grouped according to each lithology and alteration set (LA), and are presented in Figure 1. The averages obtained are indicated with an X.

Statistical tests were carried out (Anderson and Darling, 1952). The tests show that the solid density fulfills a normal distribution, with a 2.68 g/cm³ average and a 0.07 g/cm³ standard deviation for the whole population. These values are close to those found in tailings of several mining operations.

It is important to point out that the solid density has a different variability in each LA group, and this suggests that the previously mentioned average values should be used with caution.
Particle-size distribution

Characteristic sizes $d_{10}$, $d_{50}$ and $d_{80}$ were obtained for each of the particle-size distribution curves. Figure 2 shows $d_{80}$ as an important example of the results (the averages obtained for each LA, are shown with an X).

![Figure 2 Characteristic size $d_{80}$ per lithology-alteration set](image)

The average $d_{80}$ for all determinations was 151 µm with a 30 µm standard deviation. The values obtained varied from 65 to 210 µm. Figure 2 shows that the LA 8 and LA 9 groups are the ones that have the highest variability, and group LA 8 particularly, shows values within the extreme ranges of the ten set of analyzed tailings.

Rheology

The slurries were measured by varying the concentration between 50% and 70%. The rheograms obtained were interpreted using the Bingham (1922) model. The choice of this model was based on good reasons:

- It is a simple model.
- Determining parameters is straightforward and easy.
- The yield-stress value obtained is generally conservative.
- Bulk viscosity tends monotonically towards plastic viscosity, and not towards 0, when the angular deformation rate grows indefinitely.

The Bingham model is shown in equation 1.

$$\tau = \tau_0 + \eta_0 \cdot \gamma$$  \hspace{1cm} (1)

In which,

- $\tau$ : shear stress [Pa]
$\tau_0$: yield stress [Pa]

$\eta_0$: viscosity [mPa·s]

$\gamma$: shear rate [1/s]

Figures 3 and 4 show yield stress and viscosity values for each sample, obtained at 60% solids with application of flocculants at a 15 g/t dose. The graphs have been built grouping the results into each lithology-alteration set (LA). The average of each group is presented as an X in each group. The results were normalized with respect to the maximum value.
A significant difference in maximum yield stress and viscosity reached by each set, and in their averages, is shown, even if the highest values are not taken into account (in this case, five samples for yield stress and for viscosity, all highlighted in the graph). These differences may have a negative impact on thickening, transport and deposition since there will be a different behavior as each lithology and alteration set is processed. This should be taken into account in the design, planning and processing of these ores and tailings.

The influence of a specific mineral (for example, clays or micas) over rheological behavior was not detected as a straightforward and simple relationship. This suggests that the relationship between the presence and/or absence of a specific mineral and the rheology of the sample, is complex, so this behavior should be analyzed as mineralogical groups, taking all their components into account.

The relationship between the yield stress and viscosity of each sample when there is an increase in the concentration of solids was successfully modeled employing the Heymann, Peukert and Aksel (2002) equations for yield stress and the Krieger and Dougherty (1959) equations for viscosity.

The results enable the determination of the maximum concentration of solids that would ensure a stable operation, without exceeding the maximum yield stress and viscosity values considered as acceptable for the design.

Figures 5 and 6 graphically present, as an example, the experimental results and the model obtained for one sample of the LA 1 group.
Figure 5  Yield stress at different solid mass fractions (testing conducted with flocculant)

Figure 6  Viscosity at different solid mass fractions (testing conducted with flocculant)

Settling Velocity

Figure 7 shows the settling velocity results normalized regarding the maximum value of all the experiments, for a concentration of solids in weight of around 10% and with 15 g/t of flocculant. The averages obtained in each LA are shown with an X.
The settling velocities of the tailings exhibit high variability in each lithology and alteration set. The lower settling velocities were shown by sets LA 4, LA 8, LA 9 and LA 10. This implies that during the process, the corresponding thickened tailings will reach concentrations lower than required. This information will be essential for the detailed planning of the operation of thickening and disposal of these tailings.

CONCLUSIONS

A study of rougher tailings samples obtained through laboratory flotation tests has been conducted. This methodology has enabled the analysis of the rheological and settling behavior of ten sets of tailings taken from ores with different lithologies and alteration.

Analyses were carried out in order to correlate the effect of a single mineralogical variable over the behavior of these samples: the result is mediocre. This shows that the behavior of the tailings that were studied must be analyzed considering a sum of effects.

However, the results of this study demonstrate that information should be obtained for the design and operation of the tailings management facilities according to the representativity of each of the lithology and alteration group in the studied deposit.

Using this methodology, complemented with an analysis that allows correlating the mineralogy of the deposit with the rheological and settling behavior, the rheological and settling variables expected from the tailings could be integrated into the geological and metallurgical knowledge of the deposit.

REFERENCES


